Chapter 3 – The Science Content Standards
High School (Grades 9-12): Physics

INTRODUCTION

Many scientists and engineers consider physics to be the most basic of all sciences. It includes the study of motion, forces, energy, heat, waves, light, electricity, and magnetism. Physics focuses on the development of models deeply rooted in scientific inquiry, in which mathematics is used to describe and predict natural phenomena and to express principles and theories. Understanding physics requires the ability to use algebra, geometry, and trigonometry. This need for math has tended to keep all but a very few students from studying physics in this country. Other countries, however, have met this challenge by introducing the concepts of physics to students over a period of several years starting in the earlier grades. Topics requiring little or no mathematics are introduced first, and students progress to more sophisticated and quantitative treatments as they learn more mathematics. The California standards emulate this successful approach. All students can learn high school physics. Many will have enough foundational skills and mathematics knowledge from their K-8 science curriculum to study motion, forces, heat and light. In high school, students should develop a working knowledge of algebra, geometry and simple trigonometry to understand and access the power of physics. Some will need to learn or re-learn algebra, geometry and trigonometry skills while studying physics. The need for such mathematics review should lessen over time as California's rigorous mathematics standards are implemented. Students who intend to pursue careers in science or engineering will need to master the physics content called for in the California standards, including the standards with asterisks.

STANDARD SET 1: Motion and Forces

Background

Motion deals with changes of an object's position over time. Inherent in any useful study of motion is the concept of force, which represents the existence of physical interactions. Although Newton's laws provide a good platform from which to analyze forces, the laws do not address the origin of forces. Fundamental forces in nature govern the physical behavior of the universe, as scientists understand it. One of these fundamental forces, gravity, influences objects with mass, but acts at a distance, or without any direct contact between the objects. The electromagnetic force is also a fundamental force that operates across a distance. These standards on motion and forces provide the foundation for understanding some key similarities - and differences - between these two types of forces. A working knowledge of basic algebra and geometry are essential prerequisites.

In earlier standard sets at lower grade levels, students were introduced to the idea that the motion of objects can be observed and measured, and they learned that a force can change the motion of an object by giving it a push or a pull. The topic of Motion and Forces at the high school level builds directly on Grade 8, Standard Sets 1 and 2, that introduced the notions of balanced and "net" forces. Students should know the difference between speed and velocity, and should be able to interpret graphs plotting relationships between two variables, such as speed versus time for linear motion. Students should also understand the vector nature of forces. The concepts of gravity and of inertia as a resistance to a change in motion should have been introduced in eighth grade.

Description of the Standards

1. Newton's laws predict the motion of most objects. As a basis for understanding this concept:

a. Students know how to solve problems involving constant speed and average speed.

The rate at which an object moves is called its speed. Speed is measured in distance per unit time (e.g., meters/second). Velocity (v) is a vector quantity, and therefore has both a magnitude – the speed — and a direction. If an object travels at a constant speed, there is a simple linear relationship between the speed or rate of motion (r), distance traveled (d), and time (t):

$$d = rt \qquad \text{(1-a-1)}$$

If speed does not remain constant but varies with time, average speed can be defined as total distance traveled divided by total time required for the trip.

b. Students know that when forces are balanced, no acceleration occurs; thus an object continues to move at a constant speed or stays at rest (Newton's first law).

If an object's velocity (v) changes with time (t), then it is said to accelerate. For motion in one dimension, the definition of acceleration (a) is:

$$a = \Delta v/\Delta t, \qquad \text{(1-b-1)}$$

where Δ is the Greek letter "delta" and stands for "a change of." Acceleration is defined as change in velocity per unit time. (Another way to say this is that acceleration is a change in distance per unit time per unit time producing acceleration units of, for example, m/s^2). Acceleration is a vector quantity and therefore has both magnitude and direction. In order to make an object accelerate, a push or a pull (force) needs to be applied. Force is another vector quantity.

A vector quantity, such as force, can be resolved into its x, y and z components, F_x, F_y, and F_z. More than one force can be applied to an object simultaneously. If the forces point in the same direction, their magnitudes are additive; if the forces point in opposite directions, their magnitudes subtract. By adding forces along a line algebraically, keeping track of the direction and sign, the net (overall) force can be calculated. If an object is subject to only one force, or to multiple forces whose vector sum is not zero, there must be a net force on the object. However, an object that is already in motion, if there is no net force on it, continues to move at constant velocity. An object that is at rest remains at rest if there is no net force applied to it. This is Newton's First Law of Motion.

c. Students know how to apply the law F=ma to solve one-dimensional motion problems that involve constant forces (Newton's second law).

If a net force is applied to an object, it will accelerate. The relationship between the net force (F) applied to an object, its mass (m), and its resulting acceleration (a), is given by Newton's second law of motion:

$$F = ma, \qquad (1\text{-c-}1).$$

If mass is in kilograms (kg) and acceleration in m/s^2, then force is measured in Newtons, with 1 Newton = 1 $kg\text{-}m/s^2$.

If the net force on an object is constant, then it will undergo constant acceleration. Under the condition of a constant force, students should be able to make use of the following equations to describe the motion of an object in one dimension at any elapsed time "t" by calculating its velocity "v" and distance from the origin "d":

$$v = v_o + at \qquad (1\text{-c-}2)$$

$$d = d_o + v_o t + 1/2\ at^2 \qquad (1\text{-c-}3)$$

In these equations, m, v_o and d_o are the mass, initial velocity, and initial position (distance from origin) of the object and "t" is the time during which the force F is applied.

d. Students know that when one object exerts a force on a second object, the second object always exerts a force of equal magnitude and in the opposite direction (Newton's third law).

This is Newton's third law of motion, more commonly stated as "to every action there is always an equal and opposite reaction." The mutual reactions of two bodies are always equal and directed in opposite directions. Mathematically, if object 1 pushes on object 2 with a force F_{12}, then object 2 pushes on object 1 with a force F_{21} such that

$$F_{12} = - F_{21} \qquad (1\text{-d-}1)$$

This is a universal law that applies, for example, to every object on the surface of the earth. Trees, rocks, buildings and cars, even the atmosphere, are all subject to the "downward" force of gravity. In all cases, there is an equal and opposite upward push exerted by the earth on the objects. Stars exist because of the balance between the inward force of gravity and the outward pressure of their hot interior gases.

e. Students know the relationship between the universal law of gravitation and the effect of gravity on an object at the surface of Earth. (See Standard Set 1m*)

Since the time of Galileo's reputed experiment of dropping objects from the tower of Pisa, it has been understood that, in the absence of air resistance, all objects near the Earth's surface, regardless of their mass or composition, accelerate downward toward the center of the Earth at the same rate of 9.8 m/s^2. In terms of Newton's second law, this can be expressed as

$$F = w = mg, \quad (\text{where } g \approx 9.8\text{m/s}^2, \text{ the acceleration of gravity}) \qquad (1\text{-e-}1)$$

The gravitational force pulling on an object is called its weight, w, and is measured in Newtons.

f. Students know applying a force to an object perpendicular to the direction of its motion causes the object to change direction but not speed (e.g., Earth's gravitational force causes a satellite in a circular orbit to change direction but not speed).

A force that acts on an object may act in any direction. The component of the force along the direction of motion changes the speed of the object, and the components perpendicular to the motion change the direction in which the object travels.

g. Students know circular motion requires application of a constant force directed toward the center of the circle.

An object moving in a circle with constant speed is said to be in uniform circular motion. The direction of motion continuously changes as a result of a force that always points inward toward the center of the circle. Such a centrally directed force is called a centripetal force. If the mass of the object is "m," speed is "v" and radius of circle in which the object travels is "r" then, the magnitude of the force causing the circular motion is:

$$F_c = mv^2/r \qquad (1\text{-g-}1).$$

Examples of centripetal forces are the tension in a string attached to a ball that is swung in a circle, the pull of gravity on a satellite in orbit around the earth, the electrical forces deflecting electrons in the a television tube, and the magnetic forces turning a charged particle.

*h. * Students know Newton's Laws are not exact but they provide very good approximations unless an object is moving close to the speed of light or is small enough that quantum effects are important.*

Newton's Laws are not exact, but are excellent approximations valid in domains involving low speeds and macroscopic objects. However, when the speed of an object approaches the speed of light (3×10^8 m/s), Einstein's theory of Special Relativity is required to provide an accurate description of mechanics. Among the major differences between special relativity and Newtonian mechanics are: 1) The maximum attainable speed of an object is the speed of light; 2) A moving clock runs more slowly than does a stationary one; 3) The length of an object depends on its velocity with respect to the observer; and 4) The apparent mass of an object increases as its speed increases.

The other domain in which Newtonian mechanics breaks down is in the realm of very small objects, such as atoms or atomic nuclei. Here the wavelike nature of matter becomes important, and quantum mechanics better describes the sub-microscopic world. Newtonian mechanics assume that if the motion of a particle is measured with great accuracy, and all of the masses and forces that are involved are also known, it is always possible to predict with equally great accuracy the future state of motion of the particle. Quantum mechanics tells us that such certainty is not always possible. Sometimes only the probability of an outcome can be predicted from a measurement.

*I. ** *Students know how to solve two-dimensional trajectory problems.*

Consider the problem of a ball of mass "m" thrown upwards into the air at an angle Θ relative to the horizontal. The motion of the ball can be resolved into horizontal and vertical components that are independent of one another. In the absence of air resistance, once the ball is thrown there are no forces acting on the ball in the horizontal direction. While it is in flight, there is one vertical force acting on the ball, gravity (i.e., F = W = mg downward). Knowing the angle and the height from which the ball is thrown and its initial velocity, it is possible to predict the path of the ball. For example, it is possible to calculate its highest point, how far it will travel before it strikes the ground, and how long it will be in the air.

*j. ** *Students know how to resolve two-dimensional vectors into their components and calculate the magnitude and direction of a vector from its components.*

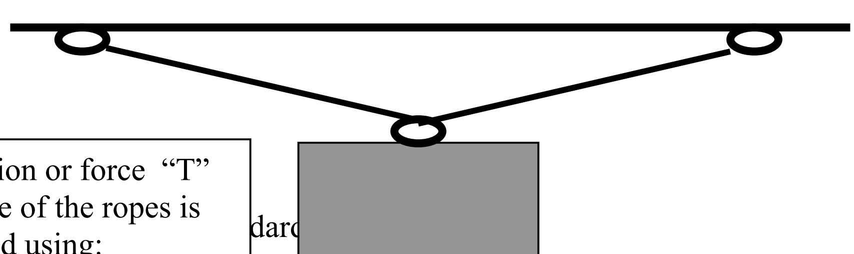
In a two dimensional system, two quantities are needed to describe a vector. A vector "r" can be completely specified by a magnitude and a direction (r,Φ), or by its "x" and "y" components, (r_x,r_y). Simple trigonometry can be applied to resolve a vector into its components (i.e., $r_x = r\cos\Phi$, $r_y = r\sin\Phi$) and to calculate the magnitude and direction of a vector from its components ($r^2 = r_x^2 + r_y^2$, $\tan\Phi = r_y / r_x$).

*k.** *Students know how to solve two-dimensional problems involving balanced forces (statics).*

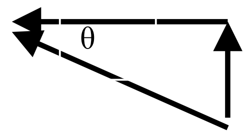
A body at rest that is subject to no net force is said to be in static equilibrium. Examples of this situation are a book resting on the surface of a table or a ladder leaning at rest against a wall. This does not imply that there are no forces acting on the object, but that the vector sum of all forces is zero. This is true for each component of the force. Thus,

$$\Sigma F_y = 0 \qquad (1\text{-k-}1),$$

where the Greek letter Σ means to sum over or add up all the force components acting on the object. One example problem is diagramed below. Students are given the weight of a hanging object, the lengths of the ropes holding it in place, and the distance between the anchors. The students are asked to calculate the forces, called tension, along ropes of equal length. This tends to be a difficult problem for students because the vector force diagram they should use to solve the problem is often confused with the physical lengths of the ropes.



The tension or force "T" along one of the ropes is calculated using:
$\frac{1}{2}$ W. = T sin(θ)



Net upward force from the pull of one rope equals one half the weight "W" of the hanging object. (The weight of ropes is ignored)

*l.** *Students know how to solve problems in circular motion by using the formula for centripetal acceleration in the following form:* $a=v^2/r$

The speed of an object undergoing uniform circular motion does not vary, but its direction does and hence its velocity. Thus the object is constantly accelerating. The magnitude of this centripetal acceleration is

$$a_c = F_c/m = v^2/r \qquad (1\text{-l-}1)$$

and the direction of the centripetal acceleration vector rotates so as to always point inward toward the center of the circle.

*m.** *Students know how to solve problems involving the forces between two electric charges at a distance (Coulomb's Law) or the forces between two masses at a distance (universal gravitation).*

Looking ahead to Standard Set 5, we see that for forces between two masses (gravitational) and two electric charges (electrostatic) at a distance, the physical nature is entirely different. However, the forces involved are both inverse square relationships. Coulomb's Law (in vacuum) is written:

$$F_q = kq_1q_2/r^2 \qquad (1\text{-m-}3),$$

where $k = 9 \times 10^9$ Nm^2/coul^2, "q_1" and "q_2" are charges (+ or -), "r" is the distance separating the charges and F_q is the force resulting from the two charges. The force is repulsive if the charges are the same sign and attractive if they are different.

Newton's law of Universal Gravitation states that if two objects have masses m_1 and m_2, with centers of mass separated from each other by a distance "r," then each object exerts an attractive force on the other and the magnitude of this force is:

$$F_g = Gm_1m_2/r^2 \qquad (1\text{-m-}1),$$

where G is the universal gravitational constant, equal to 6.67×10^{-11} Newton-m^2/kg^2. For the case of a small object falling freely near the surface of the Earth, students should understand that:

$$g = Gm_e/r_e^2 = 9.8\text{m/s}^2 \qquad (1\text{-m-}2),$$

where "m_e" and "r_e" are the mass and radius of the Earth, respectively. Students might be interested to know that Henry Cavendish's measurement of G, around the year 1800, was the last piece of information needed to calculate the mass of the Earth.

STANDARD SET 2: Conservation of Energy and Momentum

Background

The concept of energy was introduced and discussed several times in the lower grades, from physical sciences to the life sciences. In fact, every process involves some transfer of energy. In this standard, energy is classified as kinetic, meaning related to an object's motion, or potential, meaning related to an object's stored energy. The energy of a closed system is conserved. Another useful conservation law, conservation of momentum, is introduced and is shown to be a direct consequence of Newton's laws. The power and importance of these conservation laws is that they allow physicists to predict the motion of objects without having to know the details of the dynamics and interactions in a given system.

Through the standard sets in lower grades, students should have learned about forces and motion and the idea of energy. They should have been taught the role of energy in living organisms, and the effects of energy on the Earth's weather. The earlier standards also call for students to have been exposed to energy conservation, a concept that is essential to the topics contained in the high school physics standard sets 3, 4 and 5, as well as several standard sets in chemistry and earth sciences.

Description of the Standards

2. The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:

a. Students know how to calculate kinetic energy using the formula $E=(1/2)mv^2$.

Kinetic energy is energy of motion. The kinetic energy of an object in motion can be equated with the work that was needed to create the observed motion. This work can be related to the net force applied to the object along the line of the motion. The work done on an object by a force is equal to the component of the force along the direction of motion times the distance moved.

$$W = Fd \qquad (2\text{-a-}1)$$

The work needed to accelerate an object of mass m from rest to a speed v is $1/2\ mv^2$. This quantity is defined as the kinetic energy, E. The units of energy are joules, where 1 joule = 1 kg-m^2/s^2 = 1 newton-meter. Energy is a scalar quantity, which means that it has a magnitude but no direction associated with it.

b. Students know how to calculate changes in gravitational potential energy near Earth by using the formula (change in potential energy) = mgh (h is the change in the elevation).

Combine equations (1-c-1) and (2-a-1) to find the work done in lifting an object of weight "mg" through a vertical distance "h":

$$W = mgh. \qquad (2\text{-}b\text{-}2)$$

Work and energy have the same units. Thus, one can define "mgh" as the change in gravitational potential energy associated with the change in elevation "h" of the mass "m."

c. Students know how to solve problems involving conservation of energy in simple systems, such as falling objects.

Equations (1-c-2) and (1-c-3) can be used to show that if the object dealt with in Standard 2b is released from rest and allowed to fall freely, it will strike the ground with a speed:

$$v = \sqrt{2gh} \quad (2\text{-}c\text{-}1).$$

and its kinetic energy at the instant of impact will be:

$$E = 1/2\ mv^2 = 1/2\ m(2gh) = mgh \quad (2\text{-}c\text{-}2).$$

The total energy, T_e, of the object is then defined as the sum of kinetic plus potential energy:

$$T_e = E + PE \qquad (2\text{-}c\text{-}3).$$

This sum is conserved in a closed system for forces such as gravity, electromagnetic interactions, and those produced by "ideal" springs. Thus,

$$\Delta E + \Delta PE = 0 \qquad (2\text{-}c\text{-}4).$$

Therefore, the change in kinetic energy equals the negative of the change in potential energy. This is a consequence of the law of the conservation of energy. Energy can be converted from one form to another, but in a closed system the total energy remains the same.

d. Students know how to calculate momentum as the product mv.

The momentum, "p," of an object is defined to be the product of its mass, m, and its velocity, v. Momentum is thus a vector quantity, having both a magnitude and a direction. The units of momentum are kg-m/s.

e. Students know momentum is a separately conserved quantity different from energy.

If there is no net force acting on an object or a system of objects, the momentum remains constant. That is, neither its magnitude nor direction change with time. Conservation of momentum is another fundamental law of physics.

f. Students know an unbalanced force on an object produces a change in its momentum.

As discussed in Section 1c, if the net force on an object is not zero, then its velocity and hence its momentum will change. Motion resulting from a constant force F, acting on an object for a time Δt, causes a momentum change of $F\Delta t$. This change in momentum is called an impulse. Note that the units of impulse are the same as those of momentum (i.e., newton-s = kg-m/s). Depending on the direction of the force, the impulse can either increase, decrease, or change the direction of the momentum of an object.

g. Students know how to solve problems involving elastic and inelastic collisions in one dimension by using the principles of conservation of momentum and energy.

Momentum is always conserved in collisions. Collisions that also conserve kinetic energy are called elastic collisions. That is, the kinetic energy before the collision is the same as the kinetic energy after the collision. The collisions of billiard balls on smooth pool tables, or gliders on frictionless air tracks are approximate examples of this type of collision. Collisions in which kinetic energy is not conserved are called inelastic collisions. One example of this phenomenon is the situation in which a golf ball collides with a ball of putty and the two balls stick together. Some of the kinetic energy in inelastic collisions is transformed into other types of energy, such as thermal or potential energy. In all cases, the total energy of the system is conserved.

h. Students know how to solve problems involving conservation of energy in simple systems with various sources of potential energy, such as capacitors and springs.*

An ideal spring is an example of a conservative system. The force required to either stretch or compress a spring by a displacement "x" from its equilibrium (unstretched) length is:

$$F = kx \quad (2\text{-h-}1)$$

where "k" is the spring constant that measures a spring's stiffness. A graph of the magnitude of this force as a function of the compression shows that the force varies linearly from zero to kx as the spring is compressed. The area under this graph is the work done in compressing the spring and is equal to:

$$1/2 \ (\text{base})\ (\text{height}) = 1/2\ kx^2 \quad (2\text{-h-}2).$$

This is also the potential energy stored in the spring.

A capacitor stores charge. The amount of charge (Q) stored depends on the voltage (V) according to

$$Q=CV \qquad (2\text{-h-}3)$$

Where the constant “C” is called the capacitance. Notice that this is the same form as the equation for a spring. The energy stored in a capacitor is also the same form as the energy in a spring.

$$E = \frac{1}{2}CV^2$$

STANDARD SET 3: Heat and Thermodynamics

Background

The concept of heat (thermal energy) is related to all scientific disciplines. Energy transfer, molecular motion, temperature, pressure, and thermal conductivity are integral parts of physics, chemistry, biology and earth science. Thermodynamics deals with exchanges of energy between systems.

If students in high school have not yet covered the chemistry standards, it is recommended that the related topics from the chemistry standards be introduced (see Grades 9-12, Chemistry, Standard Set 4a-h, “Gases and their Properties,” and Standard Set 7a-d, “Chemical Thermodynamics”). Specific chemistry topics that are useful or necessary for promoting more complete understanding of the Physics Standard Set 3 are specifically mentioned under the detailed description sections where relevant.

At the atomic/molecular level, all matter is continuously in motion. For example, individual molecules of nitrogen, oxygen and other gases that make up the air inside a balloon move at varying speeds in random directions, vibrating and rotating. The collisions of these molecules with the inner surface of the balloon create the pressure that supports the balloon against atmospheric pressure.

There is considerable confusion in the scientific literature about the definitions of the terms "heat" and "thermal energy." Some texts define "heat" strictly as "transfer of energy." These standards use the term "heat" interchangeably with thermal energy. However, it is less confusing to reserve the term "heat" for thermodynamic situations, where energy is transferred either because of temperature differences, or work done by or on a system. In this sense, both heat and work have meaning only as they describe energy exchanges into and out of the system, adding or subtracting from a system's store of internal energy.

It should be recognized that students, just like scientists of the 18th century, might easily fall prey to the misconception that heat is a substance. Students should be cautioned that heat is energy and not a material substance, and that “heat flow” refers not to material flow but to the transfer of energy from one place to another. Confusion is most apt to arise when dealing with heat transfer by convection, that is, when heat is transferred through actual material motion along a thermal gradient. It should be pointed out that heating a material such as air causes it to expand, and results in density differences that drive the movement of heated material.

Students also often confuse temperature and heat. From a molecular viewpoint, temperature is a measure of the average translational kinetic energy of a molecule given by Eq. (3-c-1) (Grades 9-12, Chemistry, Standard Set 7). Studies of the temperature of materials as they pass through phase transitions may also help students understand the differences and relationships between heat and temperature.

To avoid confusion, it is recommended that the word "heat" be reserved for situations where heat transfer is involved, as described below.

Description of the Standards

3. <u>Energy cannot be created or destroyed, although in many processes energy is transferred to the environment as heat.</u> As a basis for understanding this concept:

a. Students know heat flow and work are two forms of energy transfer between systems.

Heat transfer can be defined as energy flow from one system to another by virtue of temperature differences or through the process of mechanical work. For example, during a phase transition from liquid to gas, heat must be added to the system. When water is heated, the input thermal energy goes first into random kinetic energy of the molecules and the temperature rises. But during a phase change, as when water is vaporized at 100°C, the internal energy of the molecules still increases but the temperature does not. This is because the energy goes into breaking intermolecular bonds, as molecules separate from their neighbors during vaporization. The energy transferred at boiling temperature produces the liquid to gas phase change, and is referred to as the latent heat of vaporization. Note that although heat is added to the system, the temperature remains constant.

Mechanical work can cause an increase in temperature, for example, when the forces of friction result in heating objects or when gases are mechanically compressed. Conversely, heating a volume of gas enclosed in a sealed container with a piston on one side causes the gas to expand and move the piston.

Heat is energy that flows between a system and its environment by virtue of a temperature difference that exists between them. The transfer of internal energy from one system to another, by virtue of a temperature difference, is known as heat flow. There are three basic mechanisms by which internal energy can be transferred from one object to another: conduction, convection, and radiation. Students should have first learned about these processes in sixth grade.

As heat is transferred to a system (object) the temperature of the system (object) may increase. Substances vary in the amount of heat necessary to raise temperature a given amount. Clearly, more mass in the system requires more heat for a given temperature change. An expression that illustrates the relationship between the amount of heat transferred and the corresponding temperature change is shown in 3-a-1. The change in temperature (ΔT) is proportional to the amount of heat added. This relationship is specified by:

$$Q = mC\Delta T \qquad (3\text{-a-}1)$$

where Q is the internal energy added by heat transfer to the system from the surroundings, ΔT is the difference in temperature between the final and initial states of the system, m is the system's mass, and C is the specific heat of the substance (in joules/gram- ^{o}C or calories/gram – ^{o}C). Specific heat is a characteristic property of a material, obtained experimentally. The unit of specific heat is energy divided by mass and temperature change (e.g., calories/gram·degree). Water is used as the standard against which all materials are compared, and has the value of one calorie/gram·degree. In other words, one calorie of heat is required to raise one gram of water one degree Celsius. When a gram of water cools one degree it liberates one calorie. This is a large value compared to other substances. What this means is that it takes much more heat to warm water than to raise the temperature of the same amount of most other substances. This has important implications for weather and climate, and is one reason the weather is "tempered" in coastal areas – cooler in summer and warmer in winter than in inland areas at similar latitude.

Equation (3-a-1) makes the distinction between heat and temperature quite clear. It specifies that heat can flow in or out of a system by virtue of temperature difference alone. There are, however, other situations where the addition or removal of heat is not accompanied by changes in temperature. This occurs when a substance undergoes a change of phase, or state, such as when water evaporates or freezes. During phase changes, the absorption or release of heat takes place while the system remains at constant temperature. For example when ice melts in a glass of water that is sufficiently well mixed, the temperature of the water remains at the freezing point of water. Additional heating of the water raises temperature only after the ice finishes melting.

b. Students know the work done by a heat engine that is working in a cycle is the difference between the heat flow into the engine at high temperature and the heat flow out at a lower temperature (first law of thermodynamics) and that this is an example of the law of conservation of energy

The total energy of an isolated system is the sum of the kinetic, potential, and thermal energies. A system is isolated when the boundary between the system and the surroundings are clearly defined. Total energy is conserved in all classical processes. Thus, the law of conservation of energy can be restated as the first law of thermodynamics, that is, for a closed system the change in the internal energy, ΔU, is given by the expression:

$$\Delta U = Q - W \qquad (3\text{-b-1}),$$

where Q is the internal energy added by heat transfer to the system from the surroundings and W is the work done by the system. The quantities ΔU, Q and W in Eq (3-b-1) can be negative or positive depending on whether energy is converted from mechanical form into heat, as when work is done on the system, or heat is transformed into mechanical energy, as when the system is doing work. By convention, Q is positive for heat added to the system and negative for heat transferred to the surroundings, while W is positive for work done by the system and negative for work done on the system. In a more practical sense, energy that cannot be obtained as work is considered a loss to the system. Thus, the first law of thermodynamics indicates how much energy is available to do work.

A heat engine is a device for getting useful mechanical work out of thermal energy. While part of the input heat energy Q_H, sometimes known as heat of combustion, is converted into useful work W, the remaining heat is lost to the environment as exhaust heat Q_L. That is, the work done by a heat engine is the difference between thermal energy input at higher temperature and heat flow out at lower temperature:

$$W = Q_H - Q_L \qquad (3\text{-b-2})$$

This simple relationship is valid for an idealized engine, also called a Carnot engine..

c. Students know the internal energy of an object includes the energy of random motion of the object's atoms and molecules, often referred to as thermal energy. The greater the temperature of the object, the greater the energy of motion of the atoms and molecules that make up the object.

The internal energy of objects is in the motion of their atoms and molecules and the energy of the electrons in the atoms. For ideal gases, nearly realized by air molecules, heat transferred to the gas increases the average speed of the gas molecules. The higher the temperature, the greater is the average speed. Note that if it were possible to observe the motion of molecules in a gas at a fixed temperature, molecules with different masses would be seen to move on average at different speeds. More massive molecules, for example, move more slowly because the average kinetic energy of each type of molecule is the same in the gas, and the kinetic energy is proportional to product of the mass and the square of the velocity of the gas molecules. The pressure of a gas results from individual molecules bumping against containing walls and other objects. Each hit and change of direction results in a net momentum change, and a net force or push on the wall or object hit. One molecule's contribution to total pressure is very small, but measurable pressures result when a large number of fast-moving atoms or molecules participate in these collisions.

For an ideal gas system at thermal equilibrium, the kinetic energy of an individual gas molecule averaged over time is:

$$E = 3/2\ kT \qquad (3\text{-c-}1),$$

where $k = 1.38 \times 10^{-23}$ joule/K and T is the absolute temperature in Kelvin (K). The Kelvin temperature scale and its conversion to the customary Fahrenheit and Celsius scales are treated in Grades 9-12, Chemistry, Standard Set 4d-e.

d. Students know that most processes tend to decrease the order of a system over time and that energy levels are eventually distributed uniformly.

All matter has some energy associated with it. Heat is observed to transfer from hot to cold objects, but not in the opposite direction. Underlying this process is the redistribution of energy among the objects in a system. A useful view of matter is that it exists in energy states or energy levels. The increments in these energy levels for most objects are so small as to be indistinguishable. A car accelerates and moves from one energy level to the next with no noticeable jumps. At the level of molecules, atoms and electrons, the allowed energy levels are separate and distinguishable. All processes that involve energy transfer ultimately end up transferring heat to surrounding materials, and energy is redistributed so that on the average a larger number of lower energy levels are occupied in the system. This can occur through friction, radiation, convection and conduction. Another aspect of the concept of order pertains to location in space. In the microscopic view of the world, order is seen as having some objects in well-defined locations. Systems of objects move to disorder according to their natural tendency to occupy more locations in space and lower energy levels in the system.

e. Students know that entropy is a quantity that measures the order or disorder of a system and that this quantity is larger for a more disordered system.

Students know from the last standard that energy transferred as heat results in the redistribution of energy among energy levels in the substances that comprise the system. This redistribution results in increasing the disorder of material substances. A quantity called "entropy" has been defined to track this process and measure the randomness or disorder of a system. Entropy is larger for a disordered system than for an ordered one. Thus, a positive change in entropy, in which the final entropy state is larger than the initial entropy state, indicates decreasing order, which can also be considered to be increasing disorder. Entropy is particularly useful as a measure of the loss of energy available to perform work.

For a system at constant temperature, such as during melting or boiling, the change in entropy is equal to:

$$\Delta S = Q/T \qquad (3\text{-e-}1)$$

where Q is the heat (thermal energy) that flows into or out of the system, and T is the absolute temperature. The units of entropy are joules/K. All processes that require energy, for example biochemical reactions that support life, occur only because the entropy increases as a result of the process.

f.* *Students know the statement "Entropy tends to increase" is a law of statistical probability that governs all closed systems (second law of thermodynamics).*

The second law of thermodynamics states that all spontaneous processes result in a state of greater disorder. When an ice cube melts and water around it becomes cooler, for example, the internal energy of the ice-water system becomes more uniformly spread, or more disordered. Most processes in nature are irreversible because they tend to move toward a state of greater disorder. A broken egg, for instance, is almost impossible to restore to its original ordered state. One way to understand the second law of thermodynamics is to consider the odds of a particular condition occurring compared to all the possible conditions for the system. Calculating the statistical probability of a condition involves counting all possible ways to distribute heat energy in a system, and the mathematics is beyond high school standards. However, most students can recognize that when work is done and heat transferred, much energy would be required to restore the system to its original state.

On completion of these standards, students will have learned the first and second laws of thermodynamics. They should understand that when physical change occurs, energy must be conserved, and some of this energy cannot be recovered for useful work because it has added to the disorder of the universe.

*g.** *Students know how to solve problems involving heat flow, work, and efficiency in a heat engine and know that all real engines lose some heat to their surroundings.*

As implied in Standard 3b, when heat flows from a body at high temperature to one at low temperature, some of the heat can be transformed into mechanical work. This is the basic concept of the heat engine. The remainder of the heat is transferred to the surroundings, and therefore is no longer available to the system to do work. This transferred heat is never zero, so some heat must always be transferred to the surroundings. Examples of practical heat engines are steam engines and internal combustion engines. In a steam engine, high temperature (T_H) steam pushes on a piston or a turbine and does work. Lower temperature (T_L) steam is then exhausted from the engine into the air. When an idealized (i.e., reversible) engine completes a cycle, the change in entropy is zero. Eq. (3-e-1) shows:

$$Q_H/T_H = Q_L/T_L \qquad (3\text{-g-}2)$$

By combining this relation with the conservation law of Eq. (3-b-2), the maximum possible efficiency, denoted as "eff," can be calculated as:

$$\text{Eff (\%)} = 100 \text{ X } W/Q_H = 100 \text{ X } (T_H - T_L)/T_H \qquad (3\text{-g-}1),$$

where efficiency is the ratio of work done by the engine to the heat supplied to the engine. The efficiency of converting heat to work thus is proportional to the difference in the high and low temperatures of the engine's working fluids, usually gases. In order for a Carnot engine to be 100 percent efficient, the temperature of the exhaust heat would need to be absolute zero, which is impossible.

STANDARD SET 4: Waves

Background

Students can be introduced to this standard set by learning to distinguish between mechanical and electromagnetic waves. In general, a wave is defined as the propagation of a disturbance. The nature of the disturbance may be mechanical or electromagnetic. Mechanical waves, such as ocean waves, acoustic waves, seismic waves, and the waves that ripple down a flag stretched taut by a wind, require a medium for their propagation and gradually lose energy to that medium as they travel. Electromagnetic waves can travel in a vacuum and lose little energy even over great distances. When electromagnetic waves do travel through a medium, they lose energy by absorption, which is why light signals sent through the most transparent of optical fibers still need to be amplified and repeated. In contrast, light emitted from distant galaxies has traveled great distances without the aid of amplification, a clue that there is a relatively small amount of material in the light's path.

Waves transfer energy from one place to another without net circulation or displacement of matter. Light, sound and heat energy can be transmitted by waves across distances measured from fractions of a centimeter to many millions of kilometers. Exertion of a direct mechanical force on a physical body, such as a push or a pull, is an example of energy transfer by direct contact. However, objects do not need to be in direct physical contact with a source of energy for transfer to occur. For instance, light transmits from a distant star, heat radiates from a fire, and sound propagates from distant thunder. Energy may be transferred by radiation, for example, from the sun to the earth, and therefore radiation also is an example of a non-contact energy transfer. Both sight and hearing are senses that can perceive energy, as information, without direct contact between the source and the sensing organ.

Note that if physics is taken before other high school sciences, it may be useful to cross-reference materials regarding pressure, heat and solar radiation from Grades 9-12, Chemistry, Standard Sets 4a and 7a, and Earth Sciences, Standard Set 4a-c. Algebra, geometry and simple trigonometric skills are required for some of the advanced topics in this standard set. Students with a good foundation in algebra and geometry can be taught the trigonometry necessary to solve problems in this standard set.

Description of the Standards

4. <u>Waves have characteristic properties that do not depend on the type of wave.</u> As a basis for understanding this concept:

a. Students know waves carry energy from one place to another.

Waves may transport energy through a vacuum or through matter. Light waves, for example, transport energy in both fashions, while sound and most other waves occur only in matter. However, even waves propagating through matter transport energy without any net movement of the matter, thus differing from other means of energy transport such as convection, a waterfall, or even a thrown object.

b. Students know how to identify transverse and longitudinal waves in mechanical media such as springs and ropes, and on the earth (seismic waves).

Waves that propagate in mechanical media are classified as either longitudinal or transverse waves. The disturbance in longitudinal waves is parallel to the direction of propagation causing compression and rarefaction, or expansion, in the medium carrying the wave. The disturbance in transverse waves is perpendicular to the direction of propagation of the wave. Examples of longitudinal waves are sound waves and “p”-type earthquake waves. Examples of transverse waves are electromagnetic or light waves, which propagate by pushing the conducting medium or moving a test particle perpendicular to the direction of propagation, and “s”-type earthquake waves.

c. Students know how to solve problems involving wavelength, frequency, and wave speed.

All waves have a velocity “v” (propagation speed and direction), which represents the rate at which the wave travels. Only periodic, sustained waves can be easily characterized through the properties of wavelength and frequency. However, most real waves are “composite,” meaning they can be understood as the sum of a few or many waveforms, each with an amplitude, frequency and wavelength.

Wavelength (λ) is the distance between any two repeating points on a periodic wave, for instance between two successive crests or troughs in a transverse wave or between adjacent compressions or expansions (rarefactions) in a longitudinal wave. Wavelength is measured in units of length.

Frequency (f) is the number of waves passing a particular point per second. As vibrations travel through a medium, frequency is the number of vibrations per second of any particle at that point in the medium. Dividing the number of cycles that a test particle makes by the time required gives cycles per second, which has the unit of reciprocal time (1/t). Frequency is measured in units of Hertz (Hz) where $Hz=s^{-1}$ (inverse second, or the number of vibrations, pulses or beats per second).

Periodic wave characteristics are related to each other. For example:

$$v = f\lambda \qquad (4\text{-c-}1)$$

d. Students know sound is a longitudinal wave whose speed depends on the properties of the medium in which it propagates.

Sound waves, sometimes called acoustic waves, are typically produced when a vibrating object is in contact with an elastic medium, which may be a solid, liquid, or gas. A sound wave is longitudinal, consisting of regions of high and low pressure, or compressions and rarefactions, that propagate away from the source. Note that sound cannot not travel through vacuum. In perceiving sound, the human eardrum vibrates in response to the pattern of high and low pressure. This vibration is translated into a signal transmitted by the nervous system to the brain, interpreted by the brain as the familiar sensation of sound. Microphones similarly translate vibrations into electrical current. Sound speakers then reverse the process and change electrical signals into vibrational motion, recreating sound waves. Acoustic waves attenuate, or reduce in amplitude, with distance, both because the energy in the wave is typically spread over a spherical shell of ever increasing area, and because inter-particle friction in the medium gradually transforms the energy into heat. The speed of sound varies from one medium to the next depending primarily on the density and elastic properties of the medium. The speed of sound is typically greater in solid and liquid media than in gases.

e. Students know radio waves, light and X-rays are different wavelength bands in the spectrum of electromagnetic waves whose speed in a vacuum is approximately $3x10^8$ m/s (186,000 miles/second).

Electromagnetic waves are transverse waves with the propagating disturbance consisting of changes to electric and magnetic fields, orthogonal to the direction of propagation of the wave and orthogonal to each other. Concepts of electric and magnetic fields are introduced in the Grades 9-12, Physics, Standard Set 5. The range of wavelengths for electromagnetic waves is very large, from less than a nanometer (nm) for x-rays to more than kilometers for radio waves. The human eye senses only the narrow range of the electromagnetic spectrum from 400 nm to 700 nm. This range generates the sensation of the rainbow of colors from violet through yellow to red. In a vacuum, all electromagnetic waves travel at the same speed of 3×10^8 m/s (or 186,000 miles per second). In a medium, the speed of an electromagnetic wave depends on both the medium's properties and on the frequency of the wave. The ratio of the speed of a wave of given frequency in vacuum to its speed in a medium is called the index of refraction. For visible light in water, this number is approximately 1.33.

f. Students know how to identify the characteristic properties of waves: interference (beats), diffraction, refraction, Doppler effect, and polarization.

A characteristic and unique property of waves is that two or more can occupy the same region of space at the same time. At a particular instant, the crest of one wave can overlap the crest of another, giving a larger displacement of the medium from its equilibrium condition (constructive interference), or the crest of one wave can overlap the trough of another, giving a smaller displacement (destructive interference). The net effect of two or more waves on a test particle is that the net force on the particle is the algebraic sum of the forces of motion of the various waves acting at that point.

If two overlapping waves traveling in opposite directions have the same frequency, the result is a standing wave. There is a persistent pattern of having no displacement in some places, called "nulls" or "nodes," and large, oscillating displacements in others, called maxima or antinodes. If two overlapping waves have nearly the same frequency, a node will slowly change to a maximum and back to a node, while a maximum will slowly change to a node and back to a maximum. For sound waves this periodic change leads to audible, periodic changes from loud to soft, known as beats.

Diffraction describes the constructive and destructive patterns of waves created at the edges of objects. Diffraction can cause waves to bend around an obstacle, or to spread passing through an aperture. The nature of the diffraction patterns of a wave interacting with an object depends on the ratio of the size of the obstacle to the wavelength. If this ratio is large, the shadows are nearly sharp, and if it is small the shadows may be fuzzy or not appear at all. Thus a ray of light, with average wavelength about 500 nm, can be blocked with a hand, but not a much longer wave of audible sound, with wavelength roughly 100 cm. The bending of water waves around a post, or the diffraction of light waves when passing through a slit in a screen are examples of diffraction patterns.

Refraction describes a change in the direction of a wave that may occur when it encounters a boundary between one medium and another, if the media have different wave velocities or indices of refraction, and if the wave front arrives at some angle other than perpendicular to the boundary. At a sharp boundary, this is observed as an abrupt angular change. However if the velocity of the wave in the medium is slowly changing, it is seen as a gradual curved bending. For example, a ray of light that passes obliquely from air to water will change its direction at the water surface, but light traveling through air having a temperature gradient can appear to have followed a curved path. A ray of light passing through a saturated solution of sugar (sucrose) and water, which has an index of refraction of 1.49, will not change direction appreciably on entering a piece of quartz submersed in the solution, since the quartz has an almost identical index of 1.51. This has the effect of making the quartz nearly invisible in the sugar-water solution.

Another interesting phenomenon, the Doppler effect, accounts for the shift in the frequency of a wave when a wave source and an observer are in motion relative to each other, compared to when they are at relative rest. This effect is most easily understood when the source is at rest in some medium and the observer is approaching the source at some constant speed. The interval in time between sensing each successive crest (the observed frequency) is shorter than it would be if the observer were at rest. The general rule, for observers moving at velocities much less than the velocity of the wave in its medium, is that the change in frequency depends only on the velocity of the observer relative to the source. Thus, the shriek of an ambulance siren has a higher pitch when the source approaches and a lower pitch when the source recedes. For an observer following the ambulance at the same speed, the siren would sound normal. Similar shifts are observed for visible light.

Polarization is another property that may occur in transverse waves, such as light.

Transverse wave are those in which the displacement of a test particle is perpendicular to the line of propagation. When the particle motion is not only perpendicular to the direction of wave propagation, but also confined to a single orthogonal plane, the wave is said to be polarized. A ray of light emitted from a hot object, such as a lamp filament or the sun, is unpolarized. In this case, the light consists of many overlapping waves such that no direction of test particle motion within any particular orthogonal plane is favored. An unpolarized light wave can become polarized when it acquires a favored axis by reflection from a sheet of glass or by passing through a material that transmits one direction or plane of transverse waves but not others. Polarizing sunglasses and stretched cellophane wrap are examples of polarizing substances.

STANDARD SET 5: Electric and Magnetic Phenomena

Background

The electromagnetic force is one of the four fundamental forces, along with gravitational force and strong and weak nuclear interactions. Electric and magnetic phenomena are fairly well understood by scientists, and the unifying theory of the electromagnetic force is one of the great successes of science. The electromagnetic force accounts for the structure and the unique chemical and physical properties of atoms and molecules. This force binds atoms and molecules, and largely accounts for the properties of matter. This force is conveyed by photons as electromagnetic energy.

Using electromagnetism for practical technological uses is taken for granted in modern society. Many devices of daily life, such as household appliances, computers, and communication, entertainment and transportation devices, are based on electromagnetic phenomena. An understanding of fundamental ideas of electricity and magnetism is basic to achieving success in many endeavors, from auto mechanics to nuclear physics.

At a fundamental level, electricity and magnetism are two manifestations of a more basic phenomenon, united as electromagnetism. The unification of electricity and magnetism under a common theoretical framework is an example of how seemingly disparate phenomena can be sometimes be unified in physics.

Studies of electric and magnetic phenomena build directly on the preceding high school physics standards, and require a thorough understanding of the concepts of motion, forces, and conservation of energy. The subject of energy transport by waves is also important. At the lower grade levels, students are introduced to electricity as they learn that energy can be carried from one place to another by electric current. They also learned about light and the relationship between electricity and magnetism. For this standard set, students will need a strong grasp of beginning algebra and geometry. Basic trigonometry is also required for some of the advanced topics. Review of several topics covered in lower grades may be necessary as part of teaching this standard set, particularly during the transition period to standards-based education. In particular, the following facts are pertinent: (1) charge occurs in definite, discrete amounts; (2) charge comes in two varieties: positive and negative, (3) the smallest amount of observable charge is the charge on an electron (or proton).

Students should be familiar with Newton's law of gravitation from previous standards, so it may be helpful to compare it with Coulomb's Law and note the key similarities and differences between the two (Grades 9-12, Physics, Standard 1-m*). They are both inverse square laws. However, the comparison should be done with attention to the fundamental differences between the two types of forces.

When discussing this standard it is important to clarify terms to avoid misconceptions. For example:

- "Direct current" (dc) is a term that refers to current that flows in one direction only. Contrast may be drawn with circuits based on "alternating currents" (ac) without detailed explanation.
- By convention, the direction of current flow is that of the positive carriers, even though the actual carriers are usually the negatively charged electrons.
- Ohm's law applies to conducting material under the assumption that resistance is independent of the magnitude and polarity of the potential difference (applied electric field) across the material.
- Generally, the difference in electric potential is the only physically significant measurement. Absolute values of potential or potential energy at a point can only be defined relative to some reference point.

It may be helpful to describe electric potential as a measure of the tendency of a charged body to move from one place to another in an electrostatic field. Further insight may be provided from noting the similarity between electrostatic potential and the gravitational potential energy of an elevated weight. In the same way, the work needed to lift a stone slowly from lower to higher position is equal to the difference in potential energy between the two locations. As students solve simple circuit problems for this standard, they will also need to know the schematic representations of the various circuit elements including a battery, a resistor, and a capacitor.

Description of the Standards

5. Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

a. Students know how to predict the voltage or current in simple direct current (DC) electric circuits constructed from batteries, wires, resistors, and capacitors.

Electric current (I) is the flow of net charge, and a complete, continuous path of current is called an electric circuit. By convention, the direction of flow corresponds to the motion of positive charges. Currents usually flow through wires made of highly conducting metals, such as copper. If a net charge (q) passes by a point (a) in a conducting wire in time (t), the current (I_a) at that point is:

$$I_a = q/t \qquad (5\text{-ab-}1)$$

In the case of uniform current "I," the rate of charge flow is the same through the entire length of the wire. Current is measured in units of amperes (Amp), which are equal to coulombs/sec (Amp = C/s) as stated in Eq. (5-ab-1).

When a particle with a charge (q) is placed in an electric field it will be subject to electrostatic forces and it will have a potential energy. Moving the charge will change its potential energy from some value PE_a to PE_b, reflecting the work W_{ba} done by the electric field (Grades 9-12, Physics, Standard 2a). Potential energy depends also on the magnitude of the charge being transported. A more convenient quantity is the potential energy per unit charge, which has a unique value at any point, independent of the actual charge of the particle in the electric field. This quantity is called electric potential, or just potential, and the difference V_{ab} between the potentials at two points "a" and "b" is termed voltage. By this definition, voltage provides a measure of the work per unit charge required to move the charge between two points a and b in the field, or alternatively it represents the corresponding difference in potential energy per unit charge "q." This is expressed as:

$$V_{ab} = V_a - V_b = W_{ba}/q = PE_a/q - PE_b/q \quad (5\text{-ab-}2)$$

Electric potential and voltage are measured in units of volt (V), which by the above definition is equal to joules per coulomb (J/C).

For a current-carrying wire, the potential difference between two points along the wire causes the current to flow in that segment.

b. Students know how to solve problems involving Ohm's law.

Resistance (R), measured in ohms, of a conducting medium (conductor) is the opposition offered by the conductor to the flow of electric charge. A potential difference V is required to cause electrons to move continuously. Ohm's Law gives the relationship between the current, I, that results when a voltage, V, is applied across a wire with resistance R, as:

$$I = V/R \qquad (5\text{-ab-}3)$$

Capacitors are charge storage devices, generally consisting of two conductors with a potential difference separated by an insulator. A typical capacitor consists of two parallel metal plates insulated from each other by a material known as a dielectric. The ability of a capacitor to store electric charge is referred to as capacitance, C, and can be measured in units of Farads. The capacitance can be found from the following relation:

$$C = q/V \qquad (5\text{-ab-}4)$$

where "q" is the charge stored (+q on one plate and – q on the other) and "V" is the potential difference between the conducting surfaces. Based on Eq. (5-ab-4), the unit of Farad is defined as coulomb/volt (C/V).

c. Students know any resistive element in a DC circuit dissipates energy, which heats the resistor. Students can calculate the power (rate of energy dissipation) in any resistive circuit element by using the formula Power = IR (potential difference) x I (current) = I^2R.

Electric power, P, is defined as the rate of dissipation of electric energy, or the rate of production of heat energy, in a resistor. This is usually called Joule's Law.

$$P = I\,V \qquad (5\text{-c-}1)$$

Using Ohm's law, this equation can also be written as $P=I^2R$ or $P= V^2/R$. P is measured in watts, where 1 watt = 1 ampere volt (W=Amp-V) = 1 joule/second.

Dissipation of energy as heat is a consequence of electrical resistance. In other words, electric power is equivalent to the work per second that must be done to maintain an electric current. Alternatively, power is the rate at which electrical energy is transferred from the source to other parts of the circuit. The unit of kilowatt hour (kWH) is sometimes used commercially to represent energy production and consumption, where 1 kWH = 3.6×10^6 J.

d. Students know the properties of transistors and the role of transistors in electric circuits.

Semiconductors are materials with an energy barrier such that only electrons with energy above a certain amount can "flow." As the temperature rises, more electrons are free to move through the material. A transistor is made of a combination of differently "doped" materials arranged in a special way. Transistors may be used to control large current output with a small bias voltage. A common role of transistors in electric circuits is as amplifiers. In that role, transistors have almost entirely replaced vacuum tubes that were widely used in early radios, television sets, and computers.

e. Students know charged particles are sources of electric fields and are subject to the forces of the electric fields from other charges.

Electrostatic force represents an interaction across space between two charged bodies. The magnitude of the force is expressed by a relationship similar to that for the gravitational force between two bodies with mass. For both gravity and electricity, the force varies inversely as the square of the distance between the two bodies. For two charges, q_1 and q_2, separated by a distance r, the relationship is called Coulomb's law:

$$F = kq_1q_2/r^2 \qquad (5\text{-e-}1)$$

where k is a constant. Customary units for charge are coulombs (C), in which case $k = 9 \times 10^9 Nm^2/C^2$

An electric field is a condition produced in space by the presence of charges. A field is said to exist in a region of space if a force can be measured on a test charge in the region. A field is an abstract concept, but allows the source of the electric force to be dissociated from its effects.

f. Students know magnetic materials and electric currents (moving electric charges) are sources of magnetic fields and are subject to forces arising from the magnetic fields of other sources.

A magnetic force exists between magnets and/or current-carrying conductors. A stationary charge does not produce magnetic forces. Furthermore, to date, no evidence for magnetic monopoles, which would be the magnetic equivalent of electric charges, has been found. In iron and other materials that can be magnetized, there are domains where the combined motion of electrons results in the equivalent of small magnets in the metal. When many of these domains are aligned, the entire metal object becomes a strong magnet. Therefore, to the best of scientific knowledge, all magnetic effects result from moving electrical charges.

The concept of a field is applied to magnetism just as it was to electricity (Physics, Standard 5e). Magnetic fields are generated either by magnetic materials or by electric currents, due to moving charged particles. A standard unit for the magnetic field strength is the Tesla (T). Electric charges moving through a magnetic field experience a magnetic force. The direction of the magnetic force is always perpendicular to the line of motion of the electric charges. The force is at maximum when the direction of motion of the electric charges, or the velocity vector, is perpendicular to the magnetic field, and at zero when the two are parallel.

g. Students know how to determine the direction of a magnetic field produced by a current flowing in a straight wire or in a coil.

By convention the direction of a magnetic field is taken be outward from the north pole and inward toward the south pole. The right-hand rule is used to determine direction of the magnetic field produced by current flowing in a wire or a coil. For a current-carrying wire, wrap the fingers of the right hand around the wire with the thumb pointing in the direction of positive current flow. The fingers encircling the wire then point in the direction of the magnetic field. The same right-hand rule is used to determine the direction of the magnetic field generated by a current-carrying coil, but the fingers now point in the direction of the current flow. The thumb will then point along the direction of the magnetic field. The correct result can also be determined using the left hand and pointing the thumb in the direction of negative current flow.

h. Students know changing magnetic fields produce electric fields, thereby inducing currents in nearby conductors.

The concept of electromagnetic induction is based on the observation that changing magnetic fields create electric fields, just as changing electric fields are sources of magnetic fields. In a conductor, these induced electric fields can drive a current. The direction of the induced current is always such as to oppose the changing magnetic field that caused it. This is called Lenz's Law.

i. Students know plasmas, the fourth state of matter, contain ions or free electrons or both and conduct electricity.

A plasma is a mixture of positive ions and free electrons that is electrically neutral on the whole, but can conduct electricity. A plasma can be created by very high temperatures when molecules disassociate and their constituent atoms further break up into positively charged ions and negatively charged electrons. Much of the matter in the universe is in stars in the form of plasma, a mixture of electrified fragments of atoms. Plasma is considered to be a fourth state of matter.

j. Students know electric and magnetic fields contain energy and act as vector force fields.*

Both the electric field, **E**, and the magnetic field, **B**, are vector fields, so they have direction and magnitude. The electric field is generally represented by "lines of force" that start on positive charges and end on negative charges (see also Standard 5m* below). The magnetic field lines are, however, closed loops – they do not have terminal points. The reason for the difference is that, unlike electric charges, no single magnetic poles have ever been shown to exist in isolation. Thus, the simplest magnetic field configuration is the dipole. Even in the simple case of a bar with magnetic field lines, which are typically represented as emanating from the north pole and entering the south pole, the lines should, in fact, be continued through the magnet, forming closed loops. For magnetic fields produced by moving charges, the right-hand rule is used to find the direction of the field along the loop (see Standard 5g, above).

Electric and magnetic fields are associated with the existence of potential energy. The fields are usually said to <u>contain</u> energy. For example, the potential energy of a two-charge system q_1 and q_2, located a distance "r" apart, is given by:

$$PE = kq_1q_2/r \qquad (5\text{-j-}1)$$

In general, the potential energy of a system of fixed point charges is defined as the work required to assemble the system bringing each charge in from an infinite distance.

*k.** *Students know the force on a charged particle in an electric field is q**E**, where **E** is the electric field at the position of particle and q is the charge of the particle.*

The electric field strength E at a given point is defined as the force experienced by a unit positive charge, E = F / q. The units of E are newton/coulomb (N/C). By this definition, the force experienced by a charged particle is:

$$F = q\,E \qquad (5\text{-k-}1)$$

where q is the magnitude of the particle's charge in coulombs and E is the electric field at the position of the charged particle.

*l.** *Students know how to calculate the electric field resulting from a point charge.*

Coulomb's law is used in calculating the electric field due to a point charge. Since, according to Eq. (5-k-1), E = F / q, the field produced by a point charge q_1 is found from substituting Eq. (5-e-1) for F, and dividing by the magnitude of the positive test charge q_2, which gives:

$$E = k\,q_1/r^2 \qquad (5\text{-l-}2)$$

The direction of E is determined by the type of the source charge q_1, so that the vector is away from + and toward -. Remember that by definition, the field strength is the force per unit positive test charge.

*m.** *Students know static electric fields have as their source some arrangement of electric charges.*

The existence of a static electric field in a region of space implies a distribution of charges as the source. Conversely, any set of charges or charged surfaces sets up an electric field in the space around the charge. To visualize an electric field, it is customary first to draw lines connecting points of equal electric potential. Electric field lines can then be drawn as the connecting lines of force perpendicular to the equal potential lines. By convention, the lines are drawn away from the charge if it is positive, and towards it if it is negative. The lines of force represent the path a small charge particle would take if released in the field.

The method used in deriving Eq. (5-l-1) can be used, in principle, to determine the field due to any distribution of charges. At each point, a net vector E is obtained by summing the vector contributions from each charge. This can be readily done for a two-charge system, where the geometry is relatively simple. For more complicated distributions, the methods of calculus are generally required to obtain the field.

*n. * Students know the magnitude of the force on a moving particle (with charge q) in a magnetic field is qvB sin(a) where a is the angle between **v** and **B** (v and B are the magnitudes of vectors **v** and **B**, respectively), and students use the right-hand rule to find the direction of this force.*

The force on a moving particle of charge "q" traveling at velocity "v" in a magnetic field B is given by:

$$F = qvB\sin\alpha \qquad (5\text{-n-}1)$$

where α is the angle between the direction of the motion of the charged particle and the direction of the magnetic field. Note that if $\alpha = 0$, then the particle is traveling parallel to the direction of the field and the magnetic force on it is zero. The maximum force is obtained when the particle is traveling perpendicular to the magnetic field. Students can determine the direction of the magnetic force through use of the right-hand rule. The magnetic force is perpendicular to both the direction of motion of the charge and to the direction of the magnetic field. From Eq. (5-n-1), it is seen that Tesla, a standard unit for the magnetic field mentioned above (Standard 5-f.) is equal to 1 N-s/C-m.

o. Students know how to apply the concepts of electrical and gravitational potential energy to solve problems involving conservation of energy.*

In Physics Standard 2a, students learned that if a stone is raised from the earth's surface, the work done against the earth's gravitational attraction is stored as potential energy in the system of stone plus earth. If the stone is released, the stored potential energy is transformed into kinetic energy, which steadily increases as the stone moves faster towards the earth. Once the stone comes to rest, this kinetic energy will ultimately be transformed into thermal energy. A similar situation exists in electrostatics. If the separation between two opposite charges q_1 and q_2 is increased, work must be performed. The work is positive if the charges are opposite and negative otherwise. The energy represented by this work can be thought of as stored in the system $q_1 + q_2$ as electric potential energy (see also standard 5j*) and like gravitational potential energy may be transformed into other forms, such as kinetic and thermal energy.

A simple example is a charge q moving freely between point a and point b, with a potential difference V_{ab} between the two points. Assuming q is positive, the change in electric potential energy is found from Eq. (5-ab-2):

$$\Delta PE = q\,V_{ab} \qquad (5\text{-o-1})$$

By conservation of energy, a corresponding amount of the kinetic energy is acquired, or released, by the charge at point b such that:

$$\Delta KE = q\,V_{ab} \qquad (5\text{-o-2})$$

By substituting the standard expression of $1/2\ mv^2$ for the kinetic energy, a variety of predictions can be made, assuming the accelerating potential does not result in velocities approaching the velocity of light. The final velocity v can be found if the charge q, the mass m and the potential V are known. This method of imparting energy to charged particles is used in devices such as televisions, and in accelerators used in modern atomic and nuclear experiments.